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Contraints on Crustal Structure from Long Period Pressure and Displacement Measurements on the Deep Seafloor

Spahr C. Webb

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Accurate estimates of seafloor shear and compressional velocities are essential for modelling long range acoustic propagation within the ocean. Compressional wave velocities have been measured using seismic refraction techniques for decades, however shallow seafloor structure is poorly resolved with sources and receivers located near the sea surface. Shear velocity is poorly known at all depths; since the ocean does not support shear propagation, only converted waves are observable at the sea surface. At MPL we have developed instrumentation capable of measuring the very small seafloor deformations resulting from very low frequency surface gravity waves (infragravity waves). By measuring a number of sites we will study the elastic changes associated with aging of the oceanic crust. We investigated the inverse problem associated with this technique which allows a quantitative connection between measured seafloor transfer functions and the elastic properties of the shallow crust.

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Abstract

Accurate estimates of seafloor shear and compressional velocities are essential for modelling long range acoustic propagation within the ocean. Compressional wave velocities have been measured using seismic refraction techniques for decades, however shallow seafloor structure is poorly resolved with sources and receivers located near the sea surface. Shear velocity is poorly known at all depths; since the ocean does not support shear propagation, only converted waves are observable at the sea surface. At MPL we have developed instrumentation capable of measuring the very small seafloor deformations resulting from very low frequency surface gravity waves (infragravity waves). By measuring a number of sites we will study the elastic changes associated with aging of the oceanic crust. We investigated the inverse problem associated with this technique which allows a quantitative connection between measured seafloor transfer functions and the elastic properties of the shallow crust.

Long Range Objectives

This project was directed at measuring the elastic structure of the shallow oceanic crust under the deep oceans. We studied the seafloor deformation driven by small amplitude, long period ocean waves (infragravity waves)

following previous work which utilized the deformation under large amplitude wind waves in shallow water. The long range goal of this project was to develop a model for shallow elastic structure as a function of crustal aging. An important part of this project was to fully understand the inverse problem associated with deriving crustal structure from the seafloor transfer function measurements.

Research Results

The following is brief revised version of a paper which is in preparation. This will serve as a comprehensive report on the research results and accomplishments on the subject grant.

Crustal Aging at the East Pacific Rise, 9°50'N, from Compliance Measurements[1]

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Scripps Institution of Oceanography,
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Abstract. Seafloor compliance was measured at three sites on a line across the East Pacific Rise at 9° 50' N, at crustal ages of 0, 0.2, and 0.4 Ma. Compliance is found to decrease with increasing age, and furthermore has a greater slope than calculated from data collected in previous studies where shear velocity (V_S) structure was inferred from compressional velocity (V_P) determinations and assumptions about V_S:V_P ratios. These results, along with knowledge of the behavior of the compliance function, suggest that crustal shear velocities increase rapidly with age, and that shallow shear velocities are less than previously assumed. This implies that much of the porosity of young ocean crust is in the form of cracks and low aspect ratio pores.

1. To be submitted to the Journal of Geophysical Researche.

INTRODUCTION

Much current research of ocean crustal structure has concentrated on oceanic spreading centers. Two popular topics of debate regarding spreading centers are the shape, longevity, and along-strike variability of axial magma chambers, and the effects of aging on young oceanic crust. Many studies have centered on the East Pacific Rise (EPR) from 8°N to 13°N, because the EPR is a moderate spreading center near to the United States. Work on this region of the EPR includes mapping active seismics (reflection and refraction, a shallow tomography experiment), and a sea-surface gravity survey.

In May 1991 a group from the Scripps Institution of Oceanography carried out a series of experiments to determine crustal structure at 9°50' N on the EPR. The expedition leg was called SERA II. The site was chosen because the EPR has a local maximum height there, which corresponds to an maximum magmatic budget, and because the ADVENTURE expedition of one month earlier at the same site reported evidence of very recent eruptions. Reflection seismics place the top of the AMC approximately 200 m below the seafloor at the axial high. This experiment expanded on an earlier sea-surface gravity experiment which was limited by only having measurements approximately 3000 m away from the seafloor, and by a possibly incorrect assumption of the average crustal density. The compliance experiment, designed to constrain V_S, used measurements of seafloor displacements (from the DOG) and stress (from a differential pressure gauge at three sites. This paper describes procedures and results of the experiment to constrain ocean crustal V_S at 9°50'N on the EPR using seafloor compliance information.

MEASUREMENTS

Seafloor pressure and acceleration data were collected at three sites on a line across the EPR. At the 0.4 Ma site (C-01), data was collected for four hours, at the 0.1 Ma site (C-08), data was collected for 31/2 hours, and at the 0.0 Ma site (L-01), data was collected for one hour and ten minutes. Data were sampled at 4 Hz, then analyzed for episodes of bad data, such as tugs on the gravimeter by its tether, rapid settling into mud or gravel, releveling episodes, and synchronization errors. Spectra, coherences and compliances were calculated using 2048-sample segments, spaced to avoid bad data episodes. Each segment was multiplied by a 4π prolate spheroidal window before application of the Fourier transform.

Comparison of the normalized compliances estimated from the three experimental sites were calculated. The uncertainties are high because the short data sampling times allowed few (7-15) windows for calculation of spectra Furthermore, an error in calibration allows us to multiply the data by any value with equal amounts of uncertainty. Therefore, the absolute level of the estimated compliances should not be trusted. Their shape, slope, and amplitude relative to one another are unaffected by the calibration problem, however, and each of these factors contains valuable information.

ANALYSIS

The most obvious feature of the three estimated compliances is the decrease in compliance with increasing age. Because compliance varies inversely with shear velocity of the crust, this trend corresponds to an increase in shear velocity with increasing age over the first 0.4 million years, in agreement with results of *Vera et al.* [1990].

Slopes of the compliance curves provide new information about crustal structure. Each of the curves has greater slope than the compliances calculated from the *Vera et al.* [1990] model. Since the *Vera et al.* [1990] models are well constrained for V_P, and density has very little effect on compliance, we conclude that the difference is due to differences in the true shear velocity profile from the profiles in that paper. The assumptions about V_S / V_P ratios used by *Vera et al.* [1990] to generate V_S models must be incorrect. Specifically, the V_S gradient must be even greater than a change from $V_S / V_P = 0.54$ at depths greater than 200 meters subbasement to $V_S / V_P = 0.43$ near the surface. If we accept the common assumption that $V_S / V_P = 0.54$ below layer 2A, V_S / V_P must be lower at the surface (and probably within layer 2A) than previously believed.

CONCLUSIONS

Seafloor acceleration and pressure time series were used to estimate seafloor compliance at three sites on the East Pacific Rise at 9° 50'N. If we assume that the three sites represent typical young (less than 0.4 Ma) oceanic crust, three conclusions are reached: to explain it, including: off-

axis volcanism or infilling of cracks by sediments, temporal changes in type of seafloor extrusion, basalt alteration, and precipitation of secondary minerals. Result 1 is consistent only with this last explanation; we believe that precipitation of secondary minerals into thin cracks is the cause of the increase in shallow crustal velocities with age.

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